Laboratory Investigations

Full body forced air warming: commercial blanket vs air delivery beneath bed sheets

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Purpose: *Single-use commercial forced air warming blankets serve only to distribute heated air from a blower. Standard bed sheets may be equally effective in delivering hot air within a lower body field and at lower cost.*

Methods: *Heated forced air at 38° and 43° was delivered within a simulated full-body field beneath standard hospital bed sheets or via a BAIR Model 315 commercial blanket. The air temperatures maintained within, as well as the caloric uptake of standard bodies containing 1000 ml water, were studied under standard simulated operating room conditions. Thermal input was provided by one Bair Hugger Model 500 Warming Unit and hospital acquisition cost for materials were calculated.*

Results: *Air temperatures measured within the full body field at the three test sites were as great or greater using bed sheets (33.4–35.8°) as with the commercial blanket (31.1–33.9°), in spite of the 5° cooler outlet temperature air settings @ 38° vs 43°, respectively (P = 0.003). Forced air delivered beneath bed sheets heated standardized thermal bodies twice as effectively as commercial blankets using identically warmed (38°) forced air and heated as well as, or better, at the 38° setting than did the commercial blanket at the 43° setting. Calculated acquisition costs for sheets vs commercial blankets were $0.76 vs $18.00 US, respectively.*

Conclusion: *The simplicity, efficacy and economy of containing 38° warm air beneath bed-sheets offer several advantages over commercial blankets and warrant further study.*

Objectif: *Les couvertures chauffantes commercialisées à pulsation d'air à usage unique ne servent qu'à distribuer l'air réchauffé d'une soufflerie. Les draps de lit ordinaires peuvent être aussi efficaces pour livrer de l'air chaud à un chant plus restreint et à meilleur coût.*

Méthodes: *De l'air chauffé à 38° et à 43° pulsé a été dirigé vers un modèle simulant un corps sous des draps d'hôpital ordinaires ou via une couverture Bair Model 315. La température maintenue à l'intérieur du champ et l'extraction calorique du modèle contenant 1000 ml d'eau ont été étudiées sous des conditions standard simulant celles de la salle d'opération. La chaleur était produite par un générateur de chaleur Bair Hugger Model 500. Les coûts d'acquisition du matériel ont été calculés.*

Résultats: *La température de l'air a l'intérieur du champ à trois sites du mesures a été aussi élevée ou plus élevée avec les draps de lit (33,4–35,8°) qu'avec la couverture Bair (31,1–33,9°), malgré le fait que la température livrée à l'orifice de sortie ait été moins élevée de 5° (38 vs 43°, P = 0,003). L'air pulsé livré entre les draps de lit a réchauffé la masse thermique normalisée deux fois aussi efficacement que la couverture Bair avec un air pulsé chauffé à la même température (38°) et a réchauffé aussi bien ou mieux au réglage 38° que la couverture Bair au réglage 43°. Les coûts d'acquisition calculés étaient de 0,76$ pour les draps et de 18$ pour les couvertures Bair.*

Conclusion: *La simplicité, l'efficacité et l'économie de la conservation de l'air à 38° entre des draps de lit constituent plusieurs avantages sur les couvertures commercialisées et justifient des études ultérieures.*

Key words
EQUIPMENT: warming;
HYPOTHERMIA:
TEMPERATURE: body, cooling, heating, monitoring.

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Recent changes in health care financing are imposing increasing pressure on practitioners to eliminate expenditures in the delivery of high quality medical care.[1] The use of forced-air patient warming systems has become commonplace and is often utilized solely to prevent thermal discomfort to patients exposed to cold operating rooms. The cost of single-use forced air blankets is considerable ($18.00 acquisition price), and limits their use in favour of blankets alone.[2] The ability of simple blankets to reduce heat loss is limited, however, when compared with forced air heating.[3] Practitioners may attempt to apply forced air directly beneath blankets for multiple reasons, including cost containment. While a standard hospital bed sheet can easily be tucked around the edge of an operating table to contain warmed forced air within a full-body field, no data are available for thermal delivery using this method. It is of interest to determine if effective heat delivery via simple bed sheets is possiblé as reduction in user costs would likely result, particularly as sheets are already available and in use to cover patients coming to the operating room to limit heat loss and nudity.

Because the application of 43° forced air has resulted in skin burns via commercial blankets, the use of air heated closer to body temperature (38° setting) may further increase overall safety.[4,5] For these reasons, the 38° setting was chosen as the maximal safe and available temperature for use directly beneath bed sheets. This was compared with conditions found with the commercial Bair system set at maximum delivery. If equivalent air temperatures and comparable heat transfer to the same standardized thermal body occur within a standard field with both methods, then heat delivery can be considered equivalent. In order to examine comparatively thermal delivery of both systems within the full body field, standardized conditions were chosen to exclude thermal input and heat redistribution within the field, while subjecting the field itself to unabated and typical ambient air conditions found in an operating room. Hospital acquisition costs for materials were obtained to calculate utilization expenses.

Methods

The geometric relationships presented by a patient's body within the lower-body field were simulated using a standard operating room table in an operating room. Two hospital bedspreads were rolled and folded to simulate the patient's legs and feet on an operating room table. A third blanket was folded within a plastic bag to form the thoraco-abdominal portion of a "patient," thus providing an air-tight "skin," against which the cranial margins of both blanket-systems could lay without adhesive application and simulate clinical conditions of closure at this point (Figure 1).

Temperature was continuousy measured at all sites using standard patient monitoring equipment: YSI400 Mon-a-therm skin temperature probes (Mallenkrodt Medical, St. Louis, MO) via a Spacelabs Model 90303B monitor (Redmond, WA) to provide temperature readings of ±0.2°C. These temperature probes correlated with each other when exposed to room air and were maintained intact at each study site to provide accurate comparative temperature measurements and on-line recording. Bair Hugger blankets (BA) were studied alternating, after a cooling period of 20 min, with bed sheets (SH), to study thermal conditions ($n = 10$ for each test condition) using each method, to insure use of room temperature materials and minimize the introduction of systematic error. Room temperature was maintained at 20° ± 1.0°C and continuously monitored and recorded with the same Spacelab/Mon-a-therm system. A Bair Hugger Model 500 Warming Unit (Augustine Medical-Eden Prairie, MN) was connected in a standard fashion to introduce warmed air from the foot end of the operating room table in all instances (Figures 2 to 4). Air delivery via a Bair Hugger Model 315 multi-access full body blanket placed as per manufacturer's directions was compared with unfolded bed sheets as follows: The outlet hose from the warming unit was supported at the foot of the table in the midline and with the opening of the hose at the level of the mattress surface. Once positioned beneath the bed sheet, the sheet was closely tucked between mattress and hard table top to seal this end, with the outlet opening directed upwards towards the ceiling beneath the sheet. The free edges of the sheet were similarly tucked around both lateral edges and the foot end of the operating room table, to contain warmed air beneath the sheets and seal against air leakage, without tension developing across the table. A second hospital bed sheet was folded lengthwise and placed over the first sheet to hang freely at the edges. The free edge of the sheets at the "cranial" end of the table were simply folded back across the "nipple-line" to cover only the same surface area as the Bair Hugger blanket (Figures 3 and 4).

Bair Hugger warming units are present in each operating room as standard items in this institution. Electrical current utilization was considered equal under both conditions and costs were calculated based on the hospital acquisition costs for commercial Bair blankets, bed-sheets and cleaning the reusable sheets. Costs for cleaning of bed-sheets, uses per sheet purchased and current hospital acquisition costs were obtained from responsible hospital department's data.

FIGURE 1 Blankets are in position to simulate the geometry of a human body within the full body field, shown before the test blanket is applied. The locations of temperature probes are indicated by arrows. The heating unit is seen introduced from the foot end in this and subsequent photographs.

Delivered air temperatures

During the first series of measurements, designed to define air temperatures maintained within each delivery system, temperature was continuously measured at four sites: (1) immediately inside the end of the outlet hose distal from the warming unit, (2) upon the surface of the table midline between the "Feet" (6–8 cm from the end of the table and outlet hose), (3) at the surface of the table between the blankets where they joined to form the "groin," three feet from outlet hose, and (4) upon the surface of the "chest-xyphoid" 6 cm from the edge of the sheets or Bair hugger blanket, located opposite where the outlet hose entered the full body field. The probes at the "feet" and "groin" were taped directly to the sheet covering the upper surface of the operating room table and the "xyphoid" probe was taped to the plastic skin of the "chest." All probes were positioned with the sensor surface facing upward away from the

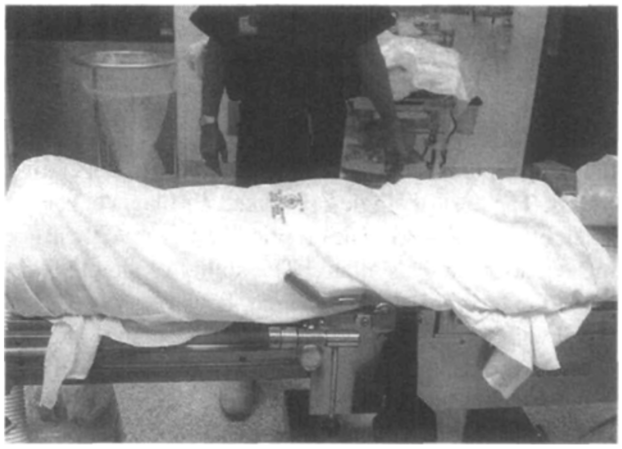

FIGURE 2 The bed sheets have been applied and tucked around three edges without tension across the upper surface. The forced air warming unit has not been activated.

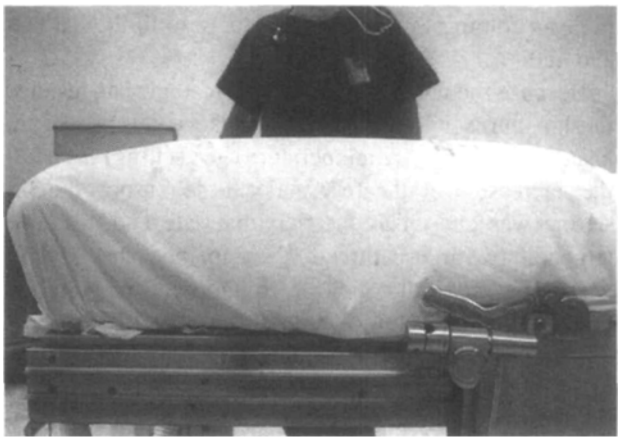

FIGURE 3 The same conditions as in Figure 2 after the forced air warmer has been activated. The blanket inflates to create a "hot house," within which, warmed air circulates vigorously.

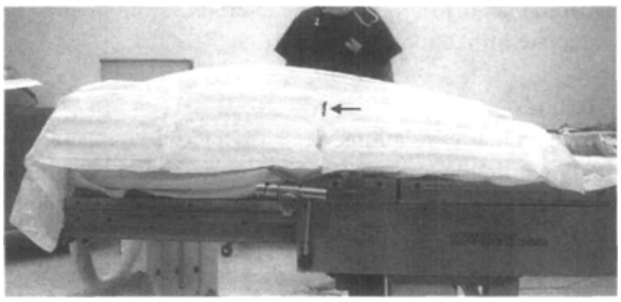

FIGURE 4 The Bair commercial blanket in use. The arrow demonstrates a view through and beneath the opening in the commercial blanket with the clothing of the individual standing behind the table appearing as a dark object at the arrow.

supporting surface. The warming unit was run for 30 min at maximum setting (43°) using the Bair Hugger or at 38° while using the sheets, then at ambient temperature for 15 min to cool. Temperatures were recorded at all four sites at minute intervals during the first five minutes of heating and then at five minute intervals.

A repeat-measures ANOVA for statistical significance was performed to evaluate the effect of SHEET vs BAIR forced air delivery upon temperatures effected at the three test sites. A two-tailed "a posteriori" statistical evaluation occurred to determine the significance for differences in warming temperatures measured at each thermometer position at five minute intervals for SHEET vs BAIR conditions.

Heat transfer

To demonstrate heat transfer within both forced air delivery systems as described above, one YSI400 Mon-a-therm skin temperature probe was secured centrally and completely between two plastic 500 ml large volume parenteral Lactated Ringers solutions (Baxter Inc., Deerfield, IL), to create standardized thermal bodies. Over/underfill volumes were eliminated to insure 500 ml content per unit by weight. Two 500 ml bags were taped together and placed such that the plane containing the temperature probe between the bags was perpendicular to the upper surface and parallel to the length of the OR table. This provided equal and maximum exposure of the surface areas of each 500 ml unit. Start temperatures of thermal bodies were 20.00 ± 3.0°C. Air temperature in the field was measured with one Mon-a-therm probe placed on the surface of the OR table as above and equidistant between both Thermal Bodies. Room temperature was again maintained at 20° ± 1.0°C. One Standard thermal body each was placed at the "Feet" and "Groin" location as described above. Thermal Body temperatures and air temperature within the field were continuously monitored over three hours during heating and recorded at 10 min intervals. Using bed sheets heated @ 38° and commercial blankets at 38° and 43°, data were collected twice under each test condition and results averaged for evaluation of each site and condition. Delivered energy to each standard thermal body (STB) was calculated via equation #1 (T = measured temperatures).

$$E_{Delivered}\,(cal \cdot STB^{-1} \cdot 3hr^{-1}) = 1\,(cal \cdot ml^{-1} \cdot C^{0-1}) \times 1000\,(ml \cdot STB^{-1}) \times [T_{3hr} - T_{start}\,(C^{\circ})]. \quad \text{(Eq. 1)}$$

Results

With the warming unit activated, warm air was introduced and created a pillow of air beneath the sheets, with the three layers of sheets floating above this air cavity (Figures 2 and 3). The Bair blanket inflated to maintain a rigid and arched shape, to develop considerable distance between the blanket and simulated body's upper surface (Figure 4).

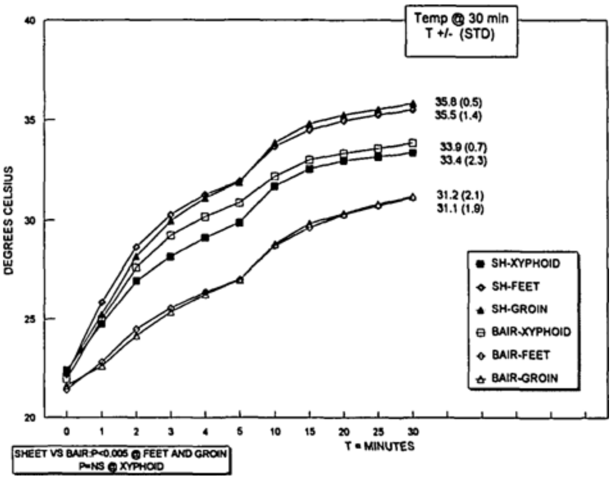

FIGURE 5 The increase in air temperature at each site is shown, initially at one minute intervals over the first five minutes and then at five minute intervals. The mean ± SD temperatures found at 30 min for each site appear at the right of each individual curve. (n = 10 for each group and site.)

Delivered air temperatures

Mean air temperatures at all field test sites increased rapidly throughout the test period, reaching a plateau at 25–30 min (Figure 5). Mean temperatures measured at the outlet hose rose much more rapidly, achieving steady state after only 5–10 min of 42.6 ± 1.0 vs 38.7 ± 0.3 for BAIR and SHEETS, respectively. The temperatures measured at "Feet" and "Groin" were warmer using bed sheets at all times throughout the heating period (P = 0.000). The temperatures measured at "Xyphoid" differed between groups. The peak temperatures ±SD measured for BAIR and SHEETs at 30 min are shown numerically at the right in Figure 5 for the three field sites. In spite of the four degree lower outlet temperature delivered via bed sheets, measured field temperatures at all sites were as high or higher than those found under the BAIR blanket. Bed-sheets were rapidly applied as described, requiring only 60–120 sec, similar to BAIR blanket application.

Heat transfer

Heat transfer to the thermal bodies occurred only very slowly (Figure 6), in spite of the low (room vs human body) starting temperatures and high [surface area:volume] ratio of the standard thermal bodies (0.06 $m^2 \cdot kg^{-1}$, comparable with that of a newborn or three times higher

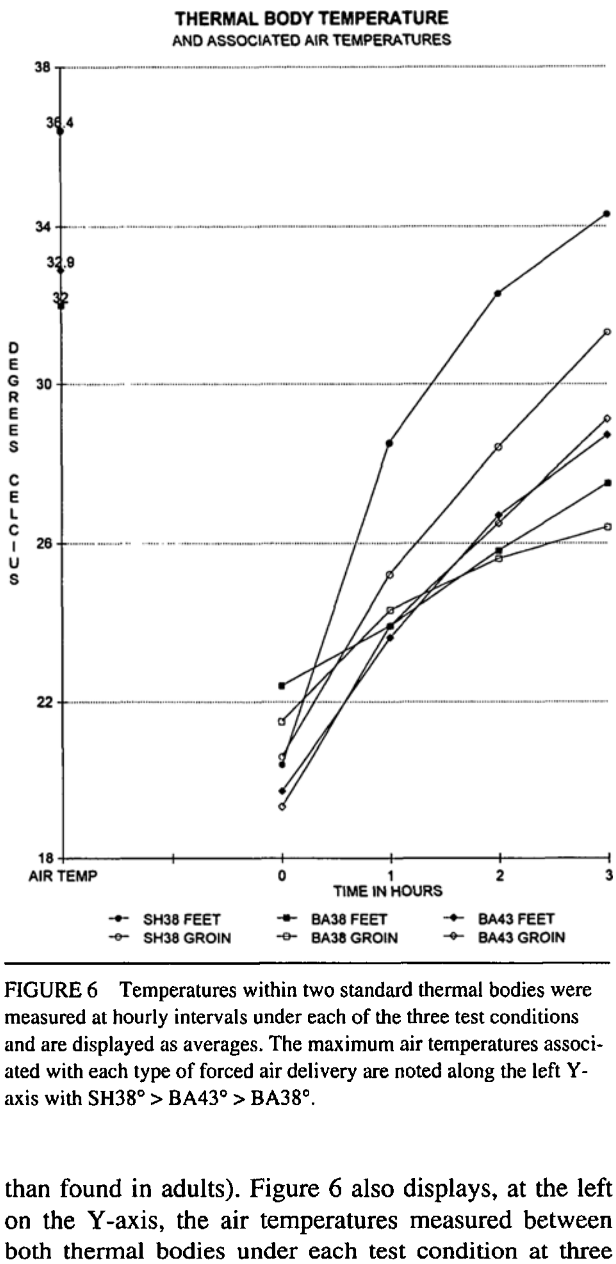

FIGURE 6 Temperatures within two standard thermal bodies were measured at hourly intervals under each of the three test conditions and are displayed as averages. The maximum air temperatures associated with each type of forced air delivery are noted along the left Y-axis with SH38° > BA43° > BA38°.

than found in adults). Figure 6 also displays, at the left on the Y-axis, the air temperatures measured between both thermal bodies under each test condition at three hours. Temperatures increased most quickly and to a higher final temperature under the conditions utilizing bed sheets, particularly when measured nearest the outlet hose (i.e., @ "Feet"). The Bair blanket transferred only between 40–91% as much thermal energy at any given site as the SHEET method (Table).

Costs

This institution purchases bed-sheets at \$5.90 US each, and obtains 52 uses per life of the sheet. Each laundry cycle costs \$0.27 US per sheet. This results in an overall cost of \$0.76 US per pair of sheets used, vs \$18.00 US acquisition price per single use commercial Bair Hugger blanket.

TABLE Energy delivered to standard thermal bodies

Location	*Groin*	*Foot*
Sheets @ 38°	10.7	13.4
Bair @ 38°	5.2	5.4
Bair @ 43°	9.8	9.0

Kcal in three hours. $n = 2$ at each site for each group.

Discussion

This study evaluated, for the first time, a novel method of forced warm air delivery and compared its performance with that of the common commercial (Bair) method. The establishment and maintenance of a thermal environment and direct transfer of thermal energy to a non-exothermic standard body was evaluated under standardized, simulated operating room conditions. The highest temperature encountered beneath the Bair blanket was 34° at the xyphoid position using 43° (maximal) settings. Thus, maintenance of patient core normothermia beneath commercial blankets must be dependent upon endogenous heat production within a thermally neutral environment: 34° air will not heat tissues to 37°. Sessler *et al.* demonstrated that maximal heat transfer via Bair forced air warming in awake adult humans approached only 10–20% of the basic metabolic rate of thermogenesis.[5] He and others noted that, in awake humans, heat transfer declined markedly after the first 40–60 min of forced air warming.[6] Heating was localized primarily to extremities, which had been previously uncovered and thus cooled for two hours. The temperatures of extremity tissues were not indicated in Sessler's study, but must have been below normothermic core temperatures: Upon institution of forced air warming, core temperature first decreased and did not return to the baseline for one to two hours.

The rate of heat transfer is known to decrease as the warmed body's temperature approaches that of surrounding air. This is evident in this study, as the hourly decline in slope of the curves in Figure 2. The low initial temperature of the thermal bodies and high surface area to volume ratios served to facilitate heat transfer. However, warming occurred very slowly with either forced air method, resulting here in only 5–10 $cal \cdot g^{-1}$ increase over three hours. Thus it was essential and useful to eliminate all thermal production within the full body field, to measure and compare the encountered low rates of heating. While the standard thermal bodies differed greatly from the human body, a sufficiently sensitive and standardized method resulted to demonstrate the comparative efficacy of bed sheet containment of heated air. Living tissues exhibit variation in evaporative heat loss, blood flow, and hormonal, diurnal and postprandial exothermic heat production, which were intentionally avoided using the standard thermal bodies. While an increased rate of heat transfer may have been possible by agitating the water within the thermal bodies, it may have introduced an additional source of heat (friction), which was avoided.

The increased heat transfer using sheets is most readily explained by the greater volumes of heated air leaving the warming unit per unit time, as well as a greater resultant air flow velocity and convection beneath the bed sheet. The pressure generated within the commercial blanket impedes the ability of the blower to create forward air flow and this backpressure is apparent as the inflation pressure of the blanket (unlike the bed sheets which are readily compressed). Airflow from the blower fluctuates considerably due to resistance at between 28–35 cu $ft \cdot m^{-1}$ when connected to commercial blankets according to the manufacturer's specifications, decreasing flows found in association with smaller styles of Bair blankets (increased resistance).* While vigorous air convection occurs below the bed sheets, considerable airflow was noted to be leaving only at the upper end of the sheet along lateral aspects of the simulated thorax.

Forced air is delivered via pinholes spaced 18 mm apart in the lower surface of the Bair blanket. In comparison with bed sheets, a diffuse and laminar style airflow pattern of *low velocity* is emitted from the pinhole gridwork pattern of the undersurface of the Bair blanket. Here, air movement can be interrupted by solid surfaces and stagnant air pockets between solid surfaces. Forced air may not penetrate to valleys distant from the blanket surface: Bair groin and foot sites were much closer to the outlet hose opening but separated further (4–8 cm beneath) from the Bair blankets active undersurface. The Bair blanket heated better at the xyphoid site, where the blanket was within millimeters of the temperature probe, yet maximally distant from the outlet hose. The rigid nature of the inflated Bair blanket also inhibits close approximation to non-planar underlying structures and may facilitate influx of ambient air or egress of warm air (Figure #4). In comparison, the highly convective wind created under the sheets was not impeded from intimate and direct contact with the underlying surfaces or thermal bodies by an interposed layer of paper, as found with the Bair blanket. These multiple factors explain the lower temperatures found beneath the commercial blankets, while airflow characteristics help to explain the comparitively reduced heating found at the xyphoid using bed sheets. The cost of monitoring forced air delivery beneath bed sheets was not considered in comparing the two methods, for several reasons: Temperature monitoring is required by the manufacturers whenever forced air is applied clinically, making only the outlet hose temperature measurement "extra." One might expect that an FDA approved biomedical device set to deliver 38° air would be unlikely to generate excessive temperatures, making it unnecessary to monitor outlet temperatures, when run at this setting. The manufacturer's specifications are variable, making it necessary to establish and insure safe output temperatures for each individual device. Continuous monitoring of outlet temperature would prevent the possibility of inadvertent switching to 43°, particularly as 45–46° air may ultimately be emitted and result in skin burns. The disposable temperature probe used here is cheap and remained functional within the outlet hose completely throughout this study. The life-span (and cost per single use) with this type of utilization is unknown, but was < $0.10 US per measurement. This might be added as a method specific cost, but without raising the cost to that of commercial blankets. Our Spacelab monitor is able to monitor two sites as a baseline, so that additional hardware was not needed in our facility to monitor the second site (outlet temperature). Reusable probes are also alternatives and can be left within the hose over multiple uses at a low but finite cost. These considerations may effect costs at other institutions. The low price-tag of "bed sheet" air distribution may facilitate useful and pleasurable thermal conditions perioperatively for more patients and without the restraints of cost containment, given this widespread availability of warming units in the USA. The basic principle of bed sheet air delivery could also be applied to awake and cooperative (resting) patients in regular hospital beds, given sufficiently large sheets, using multiple sheets tucked lengthwise across the hospital bed, or as described here, when patients are on narrow gurneys in PACU or pre-op areas.

This study was done to evaluate the efficacy of using standard, reusable bed sheets as an alternative to expensive disposable blankets in simulated clinical situations. Using the 38° settings, the maximum temperatures measured at any time were unlikely to cause burns, reaching 38.2° below the sheets and 39.3° at the outlet. Thermal injury has been previously noted using Bair Hugger blankets at high settings.[4] Should defects in the undersurface of the commercial blanket or abnormally high temperatures (outlet temperatures 43 ± 3° per manufacturer specifications)* and sufficient airflow occur, burns may result. Burns have been reported using intact paedi-

*Personal communication: R. J. Vosskuhler, Augustine Medical, Inc.

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atric blankets when used as per manufacturer specifications.[5] Thus, the use of the submaximal 38° setting was chosen for comparative testing under bed sheets conditions and was found to be adequate. The possibility of thermal injury to skin warmed by hot air increases with increasing air temperatures. Safety dictates that air temperatures reaching the patient surface be limited to only a few degrees above normal body temperature and limits the ability to heat normothermic tissues actively. Thus, delivering forced air at any temperature setting with sheets should be done only under close monitoring of outlet and patient temperature, unless warming units are developed or modified specifically for this method of application. Manufacturers will only guarantee the safety of the warming units when used with their specific commercial blanket. Using available forced air warmers without commercial blankets places the responsibility of patient safety on the individual implementing the non-approved method. Clearly, delivery of air regulated closely at 38° via sheets may be as effective as the commercial blanket set at 43°, where thermal injury has been reported, but with potentially lesser risk of burns. These findings indicate that cheaper, equally effective and potentially safer methods of patient warming are possible. The availability of forced air warmers and concomitant use of commercial blankets will continue, and the treatment and prevention of severe hypothermia in patients at risk for hypothermia is possible. Many patients will require lower-body operative field exposure, which will necessitate commercial blankets to cover upper body fields. However, it appears that hypothermia is best prevented, and inexpensive methods will contribute to their availability and use in the increasingly cost conscious field of health care.[7,8] A recent report described perioperative normothermia secondary to forced air warming as a factor in decreasing wound infections and the duration of hospitalization in patients undergoing colon resection.[9] The importance of forced air *warming* in this study over "standard measures" is mitigated, because active *cooling* of patients using "room temperature" abdominal irrigation fluid and forced air via commercial blankets. The forced air increased convective and evaporative heat loss vs typically "standard" operative measures, i.e., blankets. None the less, infection control and shorter periods of hospitalization have been recently added to the list of potential benefits associated with patient warming resulting in perioperative normothermia.

As forced air warming becomes increasingly important in maintaining intraoperative normothermia in all patients, the ability to reduce the associated costs of this treatment gain importance. Development of commercial blowers specifically designed for direct airflow beneath sheets or drapes may be needed to insure patient safety and effect unrestricted application of forced air patient warming, without the current constraints of cost containment.

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